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Pressure treatment of bamboo culms of three Vietnamese species with boron and CCB preservatives

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Abstract: Culms of three common Vietnamese bamboo species, *Bambusa stenostachya, Dendrocalamus asper* and *Thyrsostachys siamensis,* were pressure-impregnated using various schedules for obtaining adequate retention. Two preservatives were applied: a mixture of borax and boric acid (BB) and a mixture of sodium dichromate, copper sulphate and boric acid **(**CCB). Culm parts from the bottom and middle section were investigated at two moisture levels with pressures of 2.5, 4.0, 5.5, 7.0 and 8.5 bar for 60, 90 and 120 min., respectively. The penetration and retention of the preservatives were evaluated to arrive the appropriate schedule. For indoor use with a retention of 4 kg/m^3 BB, *T. siamensis* needs a pressure of 4 bar for 60 min., the bamboos *B. stenostachya* and *D. asper* a pressure of 5.5 bar for 60 min. For outdoor application with a retention of 10 kg/m^3 CCB, *T. siamensis* requires 5.5 bar for 120 min., but *B. stenostachya* 7 bar pressure for 60 min., and *D. asper* for 120 min.

Keywords: Bamboo culms, pressure treatment, efficient schedules.

INTRODUCTION

Bamboo culms are susceptible to insect and fungal attack and will be deteriorated with time, thus limiting their use for constructions and long-lasting products. The protection of bamboo is essential for extending its durability and service life. To obtain sufficient protection, different preservative methods are followed of which the pressure method is the most effective one. It provides fast production of treated culms on a large scale (Liese and Kumar, 2001).

In Vietnam, the export of bamboo products has recently increased. According to the Department of Foreign Trade 2009, bamboo furniture is one of the lead products for export on a large scale. Manufactures generally adopt the vacuum pressure impregnation following one schedule for all bamboo species (Tang, 2009). The method applied does not consider the different properties of bamboo species, the preservative

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and the treatment schedule. An improper treatment, as low pressure may limit the required preservative up-take, whereas a high pressure can cause cracks and collapses (Kumar *et al*., 1994). Hence, it is necessary to evaluate the pressure treatment used for the species.

In South Vietnam, *Bambusa stenostachya* (Tre Gai), *Dendrocalamus asper* (Manh Tong) and *Thyrsostachys siamensis* (Tam Vong) are the important commercial bamboos for furniture and export. Therefore, treatment schedules by pressure process were investigated for these species.

MATERIALS AND METHODS

The sample preparation and the investigation of the various treatment schedules were carried out in 2010 and 2011 at the factory of the Bamboo Nature Company, Binh Duong province and at the Faculty of Forestry, Nong Lam University, Vietnam. A detailed working plan and the treatment parameters were outlined before and the treated samples were sent to the Department of Wood Science, University Hamburg, Germany**,** for further analytical investigations.

Material

The experimental material of 3-year old culms was extracted from a 10-year old plantation in the Binh Thuan province, South Vietnam. Culms of *T. siamensis* with 9 m length, *B. stenostachya* and *D. asper* with 12 m length were cut 25 cm above ground. Culm parts of 120 cm length were taken representing the bottom and middle portion, as shown in Figure 1. For each test, nine samples were used with a total of 540 culm parts for each of the three species.

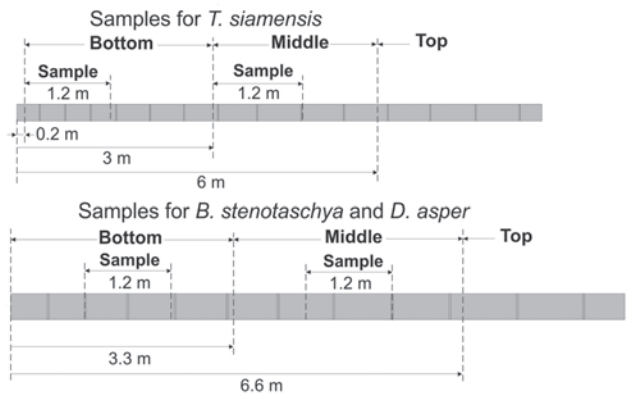

Figure 1. Location of the samples

For the cavity species, *B. stenostachya* and *D. asper*, the diaphragm was fractured by a 1 cm stick. The material was first air-dried under shade for about 5 weeks. Then, the skin was removed by machine sanding as a usual procedure in Vietnam for furniture making (Figs. 2 and 3). Further information of the samples tested is given in Table 1.

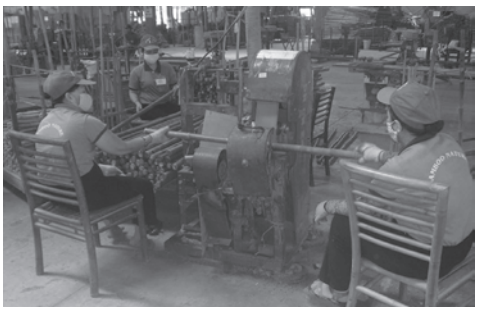

Figure 2. Skin removal by sanding, Bamboo Nature Co.

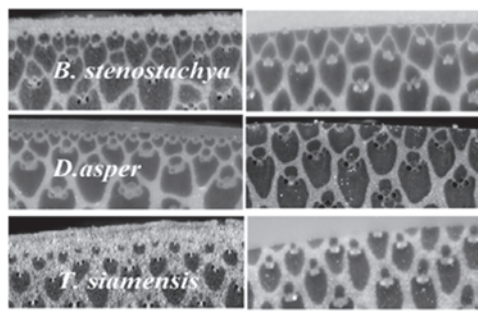

Figure 3. Cross-sectional view before and after skin removal

Table 1. Structural features of the samples tested

Bamboo species	Culm position	Culm diameter (mm)	Wall thickness (mm)	Internode length (cm)	No. of nodes
T. siamensis	bottom	46	23	18	6
	middle	39	12	28	4
B. stenostachya	bottom	81	18	27	4
	middle	70	13	36	3
D. asper	bottom	86	18	29	4
	middle	72	12	41	3

Influence of moisture content

The influence of the moisture content was investigated for two ranges, 30 - 40% and 15 - 20%, whereby the samples after air drying were placed in an air conditioning room for two and three weeks, respectively.

Preservatives

Two treatment solutions were tested: for indoor furniture 6% BB as mixture of borax and boric acid (1.5:1ratio), for outdoor structures 6% CCB containing sodium dichromate, copper sulphate and boric acid (4:3:1.5 ratio).

Impregnation cylinder

The experiments were conducted in a vacuum pressure cylinder of 40 cm in diameter and 140 cm in length. After each treatment**,** the solution was changed to ensure the same concentration.

Treatment schedules

For all impregnation schedules an initial vacuum of 670 mm Hg for 30 min. and a final vacuum of 650 mm Hg for 15 min. were applied. Five pressures of 2.5, 4.0, 5.5, 7.0 and 8.5 bar were used, each of them for 60, 90 and 120 min. Thus, in total 15 impregnation schedules were tested.

Determination of preservative uptake

The preservative retention was determined by weighing the samples before and after impregnation. The uptake was calculated as R = (A x C: 100) : V, with A as liquid absorption = final weight - initial weight; C as solution concentration and V as volume of the sample. To obtain the mean retention, the results from the nine samples of each test were averaged.

The radial depth of penetration was measured on a cross-section at the middle of the sample. The penetration was identified with staining by curcuma for boron in BB and by chrome azurol for copper in CCB. The reagents indicate BB by red color and CCB by dark blue. For each test, three replicates of the nine samples were investigated and the penetration was classified in five grades (Table 2).

Table 2. Classification of preservative penetration

Grade	Penetration of the culm wall
0	No penetration
1	<25%
2	25-50%
3	50-75%
4	>75% - complete

For determining the gradient of absorption within the culm part, 5 cm long specimens from both ends and the middle part of the sample and also the outer, central and inner layers of the middle part were investigated. From the nine samples of each test, five replicates were taken. The retention of BB and CCB was determined by analyzing the copper, chromium and boron content using the Inductively Coupled Plasma (ICP) method.

Data analysis

The data were statistically analyzed using Excel 2007 and Minitab. The differences between mean values of retention for the species, culm portion, moisture range, preservative and the treatment schedule were evaluated by means of the F-test. The regression equation of the retention with pressure and time was established by ANOVA.

RESULTS AND DISCUSSION

Penetration

The results of the preservatives penetration into the culm part are presented in Table 3**.** With a pressure of 2.5 bar, only the middle sample of *T. siamensis* had full penetration with grade 4. The bottom part of *T. siamensis* as well as both parts of *B. stenostachya* and *D. asper* obtained the low grades 1 and 2. By raising the pressure to 4 bar the penetration for the three bamboos increased to the grades 3 and 4. Pressures of 5.5 bar and higher resulted generally in the grade 4.

Table 3. Classification of the penetration of the three bamboo species treated with BB and CCB by pressures from 2.5 to 8.5 bar during three periods of time

Bamboo species	Sample	Time (min)	BB					CCB				
			Pressure (bar)									
			2.5	4.0	5.5	7.0	8.5	2.5	4.0	5.5	7.0	8.5
B. stenostachya	Bottom											
	MC2	60	2	3	4	4	4	1	3	4	4	4
		90	2	4	4	4	4	1	4	4	4	4
		120	3	4	4	4	4	3	4	4	4	4
	MC1	60	1	4	4	4	4	2	4	4	4	4
		90	2	4	4	4	4	1	4	4	4	4
		120	3	4	4	4	4	3	4	4	4	4
	Middle											
	MC2	60	1	3	4	4	4	1	4	4	4	4
		90	1	4	4	4	4	3	4	4	4	4
		120	2	4	4	4	4	3	4	4	4	4
	MC1	60	2	3	4	4	4	1	3	4	4	4
		90	2	4	4	4	4	3	4	4	4	4
		120	3	4	4	4	4	3	4	4	4	4
D. asper	Bottom											
	MC2	60	2	4	4	4	4	2	3	4	4	4
		90	2	4	4	4	4	2	4	4	4	4
		120	2	4	4	4	4	3	4	4	4	4
	MC1	60	1	3	4	4	4	1	4	4	4	4
		90	1	4	4	4	4	1	4	4	4	4
		120	3	4	4	4	4	3	4	4	4	4
	Middle											
	MC2	60	2	3	4	4	4	1	4	4	4	4
		90	1	4	4	4	4	3	4	4	4	4
		120	3	4	4	4	4	3	4	4	4	4
	MC1	60	1	4	4	4	4	2	4	4	4	4
		90	1	4	4	4	4	2	4	4	4	4
		120	2	4	4	4	4	3	4	4	4	4
T. siamensis	Bottom											
	MC2	60	2	4	4	4	4	2	4	4	4	4
		90	2	4	4	4	4	2	4	4	4	4
		120	3	4	4	4	4	4	4	4	4	4
	MC1	60	2	4	4	4	4	2	4	4	4	4
		90	2	4	4	4	4	2	4	4	4	4
		120	3	4	4	4	4	3	4	4	4	4
	Middle											
	MC2	60	3	4	4	4	4	3	4	4	4	4
		90	2	4	4	4	4	3	4	4	4	4
		120	4	4	4	4	4	4	4	4	4	4
	MC1	60	3	4	4	4	4	3	4	4	4	4
		90	2	4	4	4	4	3	4	4	4	4
		120	4	4	4	4	4	4	4	4	4	4

MC1 : 15 – 20%; MC2:30 – 40%

Retention

The preservative absorption of the three species treated with BB and CCB by pressures from 2.5 to 8.5 bar for three periods is summarized in Tables 4 a and b. Statistical analysis showed a highly significant effect of the species, culm portion, moisture content, preservative as well as of the pressure and time applied for the retention (Table 4 c).

Table 4a. Average retention (kg/m^3) of three bamboo species treated with BB according to 15 schedules

Treatment schedule		*B. stenostachya*				*D. asperB*				*T. siamensis*			
Pressure	Time	Bottom		Middle		Bottom		Middle		Bottom		Middle	
(bar)	(min)	MC2	MC1	MC2	MC1	MC2	MC1	MC2	MC1	MC2	MC1	MC2	MC1
2.5	60	3.1	3.4	3.6	4.0	2.7	3.1	3.0	3.4	3.6	3.7	3.9	4.5
		(0.9)	(0.6)	(0.7)	(1.3)	(1.2)	(0.6)	(0.9)	(0.7)	(1.1)	(0.9)	(0.9)	(0.7)
2.5	90	3.4	3.7	3.9	4.6	3.1	3.4	3.3	3.7	3.7	4.2	4.6	5.1
		(0.5)	(0.8)	(0.6)	(1.2)	(0.6)	(0.5)	(0.7)	(0.6)	(0.8)	(1.0)	(1.1)	(0.8)
2.5	120	3.6	4.2	4.3	4.7	3.3	3.7	3.8	4.0	3.2	3.7	4.5	5.4
		(0.7)	(0.5)	(0.8)	(1.2)	(0.6)	(1.1)	(0.9)	(0.7)	(1.3)	(0.8)	(0.7)	(0.9)
4	60	3.9	4.4	4.6	5.3	3.6	3.9	4.0	4.4	4.4	4.7	5.5	6.0
		(0.8)	(1.0)	(0.7)	(0.6)	(0.7)	(1.1)	(0.8)	(0.5)	(0.9)	(1.2)	(1.0)	(0.9)
4	90	4.4	4.8	4.8	5.7	4.0	4.4	4.3	4.6	4.7	5.2	6.0	6.9
		(0.9)	(0.8)	(0.5)	(1.1)	(0.8)	(0.9)	(0.5)	(0.6)	(1.0)	(1.2)	(0.8)	(0.9)
4	120	4.8	5.4	5.4	6.2	4.3	4.7	4.5	5.3	5.2	5.6	6.6	7.4
		(1.1)	(0.7)	(1.1)	(0.5)	(0.6)	(0.9)	(0.7)	(0.9)	(0.9)	(1.2)	(0.5)	(0.5)
5.5	60	5.1	5.7	5.8	6.5	4.7	5.0	5.3	5.8	5.6	6.2	7.1	7.9
		(0.5)	(1.3)	(0.7)	(0.7)	(0.9)	(0.6)	(0.8)	(0.5)	(1.4)	(0.9)	(0.7)	(0.7)
5.5	90	5.9	6.3	6.2	7.0	5.5	5.8	6.0	6.2	6.2	7.1	7.5	8.9
		(0.8)	(0.9)	(0.7)	(0.5)	(0.6)	(1.0)	(1.2)	(0.6)	(1.0)	(1.3)	(0.9)	(0.6)
5.5	120	6.7	7.1	7.4	8.4	5.8	6.7	6.4	7.0	7.2	7.8	9.1	9.6
		(0.6)	(1.3)	(1.0)	(1.1)	(1.2)	(0.7)	(1.5)	(0.7)	(1.5)	(1.2)	(0.8)	(1.0)
7	60	6.8	7.5	7.8	9.2	6.2	7.0	6.7	7.7	7.8	9.1	9.3	11.0
		(0.8)	(1.0)	(0.6)	(0.7)	(0.5)	(0.8)	(0.6)	(0.5)	(1.1)	(0.9)	(0.8)	(0.9)
7	90	7.7	8.4	8.9	10.2	6.6	7.8	7.5	8.5	9.2	10.4	10.7	12.1
		(0.7)	(1.4)	(0.8)	(0.9)	(1.1)	(0.6)	(0.5)	(0.8)	(1.0)	(1.1)	(0.6)	(0.7)
7	120	8.9	9.5	9.7	11.3	7.9	8.8	8.4	9.8	10.2	11.1	11.6	12.8
		(0.6)	(1.2)	(0.9)	(0.5)	(0.8)	(1.4)	(0.7)	(0.6)	(1.5)	(0.8)	(0.7)	(1.1)
8.5	60	9.4	10.1	10.3	11.7	8.1	9.4	9.2	10.7	11.7	12.0	13.0	13.5
		(0.9)	(1.1)	(0.8)	(1.5)	(0.7)	(0.9)	(0.8)	(1.0)	(1.6)	(1.0)	(1.3)	(0.8)
8.5	90	10.9	11.9	11.7	12.8	9.2	10.2	9.7	11.2	12.1	12.5	13.8	14.3
		(0.9)	(0.6)	(1.2)	(0.8)	(0.5)	(0.7)	(0.9)	(1.5)	(0.8)	(1.0)	(1.2)	(0.9)
8.5	120	11.4	12.7	12.5	13.8	10.0	11.2	10.8	11.9	12.7	13.2	14.4	15.5
		(1.1)	(0.7)	(1.0)	(0.9)	(1.4)	(0.8)	(1.1)	(0.9)	(1.5)	(0.9)	(1.0)	(0.7)

MC2 : 30 - 40%; MC1 : 15 - 20% ; Values in parentheses are standard deviation

Table 4b. Average retention (kg/m^3) of three bamboo species treated with CCB according to 15 schedules

Treatment schedule		*B. stenostachya*				*D. asperB*				*T. siamensis*			
Pressure	Time	Bottom		Middle		Bottom		Middle		Bottom		Middle	
(bar)	(min)	MC2	MC1	MC2	MC1	MC2	MC1	MC2	MC1	MC2	MC1	MC2	MC1
2.5	60	3.5	4.1	3.7	4.1	3.4	3.9	3.7	4.2	3.9	4.4	5.1	5.5
		(0.6)	(0.8)	(1.1)	(0.7)	(0.8)	(1.2)	(0.9)	(0.7)	(1.3)	(0.9)	(0.5)	(0.8)
2.5	90	3.7	4.3	4.9	5.2	3.5	4.1	4.2	4.4	4.3	4.5	5.9	6.1
		(0.7)	(1.3)	(0.6)	(0.9)	(1.2)	(0.8)	(1.4)	(0.6)	(1.3)	(0.9)	(0.7)	(0.6)
2.5	120	4.1	4.7	5.1	5.5	3.7	4.0	4.3	4.9	5.1	5.9	6.1	6.5
		(0.9)	(0.5)	(1.4)	(0.8)	(0.6)	(1.2)	(0.7)	(0.5)	(1.3)	(1.0)	(0.9)	(0.6)
4	60	5.1	5.4	6.2	6.7	4.4	4.8	5.1	5.5	5.5	6.2	7.1	7.9
		(0.8)	(0.6)	(0.5)	(1.0)	(0.4)	(0.9)	(0.6)	(0.9)	(1.1)	(0.9)	(1.3)	(0.9)
4	90	5.9	6.1	6.5	7.1	4.9	5.4	5.6	6.1	6.2	6.6	7.5	8.5
		(0.7)	(1.1)	(1.2)	(0.6)	(0.9)	(0.7)	(1.2)	(0.6)	(1.4)	(1.0)	(0.8)	(1.0)
4	120	6.5	6.7	7.0	7.9	5.7	6.2	6.2	6.8	7.0	7.5	7.9	9.1
		(1.0)	(0.9)	(0.6)	(1.2)	(0.8)	(0.4)	(0.5)	(1.0)	(0.9)	(1.1)	(0.9)	(0.8)
5.5	60	6.8	7.3	7.2	8.7	6.0	6.9	6.6	7.3	7.9	8.6	8.8	10.5
		(0.5)	(0.9)	(0.7)	(1.2)	(1.0)	(0.7)	(0.9)	(0.6)	(1.2)	(1.6)	(0.5)	(0.7)
5.5	90	7.5	8.5	8.6	9.6	6.6	7.8	7.5	8.7	9.1	10.1	9.9	11.9
		(1.3)	(0.7)	(1.1)	(1.5)	(0.9)	(0.6)	(0.8)	(1.2)	(1.4)	(0.9)	(0.6)	(1.4)
5.5	120	8.5	9.0	9.8	10.7	7.7	8.0	8.4	9.1	10.3	11.1	11.2	12.9
		(0.6)	(1.0)	(1.0)	(0.5)	(1.0)	(0.4)	(0.7)	(0.6)	(0.9)	(1.5)	(1.3)	(0.8)
7	60	10.1	10.9	10.8	11.8	8.5	9.9	9.0	10.7	10.9	11.5	11.8	13.1
		(0.8)	(0.5)	(0.7)	(1.2)	(0.8)	(1.2)	(1.5)	(0.9)	(1.1)	(0.7)	(1.5)	(0.6)
7	90	10.9	11.9	12.0	13.0	9.5	11.0	10.2	11.6	11.5	12.9	12.8	14.5
		(0.9)	(1.1)	(0.8)	(0.9)	(1.2)	(0.9)	(0.6)	(1.0)	(1.0)	(1.3)	(0.9)	(1.4)
7	120	12.0	12.7	13.1	14.1	10.9	11.5	11.3	12.8	12.9	13.7	14.4	15.9
		(0.8)	(0.7)	(0.6)	(1.3)	(0.6)	(1.2)	(0.5)	(0.8)	(1.1)	(0.9)	(0.7)	(1.1)
8.5	60	12.2	13.0	13.7	14.7	11.3	12.2	11.9	13.2	13.5	14.1	15.4	16.3
		(1.4)	(0.6)	(0.9)	(1.0)	(1.3)	(1.1)	(0.7)	(0.9)	(1.6)	(0.8)	(0.5)	(0.9)
8.5	90	13.4	14.2	14.4	15.5	11.7	12.4	12.9	14.2	14.3	14.9	16.1	17.1
		(1.5)	(1.2)	(0.8)	(1.4)	(1.0)	(1.2)	(0.7)	(0.7)	(1.1)	(1.2)	(1.0)	(1.0)
8.5	120	13.8	14.6	14.9	15.9	13.1	14.0	13.9	14.4	14.9	15.5	16.4	17.5
		(0.6)	(1.0)	(0.7)	(1.0)	(1.4)	(0.9)	(1.1)	(0.8)	(1.5)	(0.9)	(1.1)	(0.8)

MC2 : 30 - 40%; MC1 : 15 - 20% ; Values in parentheses are standard deviation

Table 4c. Statistical analysis of variance for the effect of species, position, moisture content, preservative, pressure and time on retention

Source	DF	Mean Squares	F-value
Species	2	122.12	10.02***
Position	1	96.72	7.70**
Moisture content	1	55.22	4.36*
Preservative	1	338.72	28.49**
Pressure	4	898.49	318.70***
Time	2	62.8	5.02**

Significant at: * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$

Absorption by the species

Between the three species, significant differences existed in the preservative retention. *T. siamensis* had the highest uptake, followed by *B. stenostachya* and *D. asper.* This is due to the different structural features. According to Hoang *et al*. (2007), the specific gravity of *T. siamensis* ranges from 0.41- 0.46 g/cm^3, of *B. stenostachya* from 0.69 - 0.74 and of *D. asper* from 0.71- 0.78. Thus, a lower specific gravity and thinner walls (Table 1) result in a higher absorption**.** An investigation on the structural features causing these differences would be worthwhile.

Preservative uptake by the culm portion

For all species, the middle part of the culms showed a higher absorption than the bottom one. Such relation was also found by Kumar *et al.* (1992), Nguyen (2005) and Wahab *et al*. (2005). Although the specific gravity is higher in the middle part than in the bottom, its culm wall is thinner and contains more vascular bundles (Grosser & Liese, 1971; Liese, 1998).

Effect of moisture content

The influence of the two moisture ranges on the preservative uptake was statistically significant (Table 4c). At all pressures applied, samples with 15 - 20% moisture had about 15% more absorption than at 30 - 40%.

Retention depending on the impregnation schedule

Generally, the treatment with BB resulted in a lower retention than with CCB, as also stated by Wahab *et al*. (2005). The preservative uptake increased significantly with the pressure from 2.5 - 8.5 bar. Regardless of culm portion and moisture content, the mean retention varied according to the pressure applied for *B. stenostachya* with BB from 3 - 14 kg/cm^3 and with CCB from 3.5 - 16 kg/cm^3. *D. asper* absorbed 2.5 - 12 kg/cm^3 of BB and 3.5 – 14.5 kg/cm^3 of CCB. The uptake of *T. siamensis* was from 3.5 - 15.5 kg/cm^3 with BB and 4 - 17.5 kg/cm^3 with CCB.

With the pressure of 8.5 bar, defects like end splits and node checks occurred in some samples of *D. asper*, whereas the other two species did not show such damage.

The period of pressure also affects the preservative uptake with increased retention. The relationship between pressure, time and retention was determined using regression analysis. Table 5 indicates a linear relationship with a high coefficient ($R^2 > 95\%$). This information could be applied in determining the treatment schedule for the species investigated relevant to the required retention.

Table 5. Regression equations for the retention of the three bamboo species with two preservatives (at 95% confidence level)

Species	Preservative	Position	Moisture content (%)	Linear regression equation	R^2
B. stenostachya	BB	Bottom	30 - 40	$y = -2.25 + 1.18 x_1 + 0.02 x_2$	0.957
			15 - 20	$y = -2.32 + 1.28 x_1 + 0.02 x_2$	0.953
		Middle	30 - 40	$y = -2.01 + 1.26 x_1 + 0.02 x_2$	0.959
			15 - 20	$y = -1.98 + 1.41 x_1 + 0.03 x_2$	0.967
	CCB	Bottom	30 - 40	$y = -2.66 + 1.59 x_1 + 0.02 x_2$	0.975
			15 - 20	$y = -2.34 + 1.66 x_1 + 0.02 x_2$	0.982
		Middle	30 - 40	$y = -2.44 + 1.66 x_1 + 0.03 x_2$	0.983
			15 - 20	$y = -2.15 + 1.77 x_1 + 0.03 x_2$	0.993
D.asper	BB	Bottom	30 - 40	$y = -1.65 + 1.01 x_1 + 0.02 x_2$	0.966
			15 - 20	$y = -1.97 + 1.15 x_1 + 0.02 x_2$	0.965
		Middle	30 - 40	$y = -1.52 + 1.09 x_1 + 0.02 x_2$	0.970
			15 - 20	$y = -1.86 + 1.27 x_1 + 0.02 x_2$	0.967
	CCB	Bottom	30 - 40	$y = -2.79 + 1.44 x_1 + 0.02 x_2$	0.975
			15 - 20	$y = -2.12 + 1.54 x_1 + 0.02 x_2$	0.977
		Middle	30 - 40	$y = -2.43 + 1.48 x_1 + 0.02 x_2$	0.980
			15 - 20	$y = -2.16 + 1.63 x_1 + 0.02 x_2$	0.983
T. siamensis	BB	Bottom	30 - 40	$y = -1.66 + 1.00 x_1 + 0.02 x_2$	0.966
			15 - 20	$y = -2.17 + 1.49 x_1 + 0.02 x_2$	0.970
		Middle	30 - 40	$y = -2.25 + 1.55 x_1 + 0.02 x_2$	0.974
			15 - 20	$y = -1.77 + 1.60 x_1 + 0.02 x_2$	0.987
	CCB	Bottom	30 - 40	$y = -2.61 + 1.67 x_1 + 0.03 x_2$	0.993
			15 - 20	$y = -2.27 + 1.71 x_1 + 0.03 x_2$	0.989
		Middle	30 - 40	$y = -1.46 + 1.73 x_1 + 0.02 x_2$	0.983
			15 - 20	$y = -1.24 + 1.86 x_1 + 0.03 x_2$	0.992

whereby y is retention (kg/m^3); x_1 is pressure time (minute) and x_2 is pressure intensity (bar)with $60 < x_1 < 120$ and $2.5 < x_2 < 8.5$

Gradient of retention along and across the culm part

The gradient of the retention within the culm part was investigated at the two ends, in the middle of the sample and on a radial section. Five replicates from each treatment schedule were tested by chemical analysis (Table 6 a, b and c).

There was considerable variation of the retention from the ends to the middle of the sample since absorption at the ends was higher due to the open vessels. Across the

Table 6a. Variation of retention (kg/m^3) for *B. stenostachya* depending on the position of sampling

Preservative	Schedule		Sample condition	along culm			radial direction		
				E1	E0	E2	Outer	Center	Inner
BB	5.5 bar for 60 min	B	MC2	6.8 a	4.9 b	6.5 a	5.5 ab	5.0 a	6.0 b
			MC1	7.2 a	5.5 b	6.8 a	5.9 ab	5.6 a	6.8 b
		M	MC2	7.7 a	5.8 b	7.2 a	6.6 ab	5.9 a	7.0 b
			MC1	9.4 a	6.9 b	8.6 a	7.5 ab	7.3 a	8.2 b
	5.5 bar for 90 min	B	MC2	7.2 a	5.6 b	6.7 a	6.4 ab	6.2 a	7.1 b
			MC1	7.8 a	5.9 b	7.5 a	6.6 a	6.1 a	7.6 b
		M	MC2	8.2 a	6.0 b	7.5 a	6.8 ab	6.2 a	7.8 b
			MC1	9.1 a	7.2 b	8.9 a	7.9 ab	7.4 a	8.9 b
	5.5 bar for 120 min	B	MC2	9.1 a	6.4 b	8.2 a	7.1 a	6.6 a	7.4 a
			MC1	8.5 a	6.7 b	8.1 a	7.6 a	7.0 a	8.9 b
		M	MC2	9.6 a	7.4 b	9.0 a	8.4 ab	7.6 a	8.7 b
			MC1	10.9 a	8.0 b	10.1 a	8.8 ab	8.3 a	9.5 b
CCB	7 bar for 60 min	B	MC2	12.8 a	10.5 b	12.0 a	11.7 ab	10.8 a	12.3 b
			MC1	12.9 a	10.7 b	12.3 a	11.8 ab	11.2 a	12.9 b
		M	MC2	13.4 a	10.9 b	12.9 a	12.8 ab	11.7 a	13.3 b
			MC1	14.4 a	11.2 b	13.8 a	12.0 ab	11.4 a	13.2 b
	7 bar for 90 min	B	MC2	14.3 a	10.3 b	13.1 a	11.3 ab	10.7 a	12.5 b
			MC1	14.9 a	11.6 b	13.7 c	13.0 a	12.5 a	14.1 b
		M	MC2	14.5 a	11.7 b	13.6 a	12.6 ab	11.4 a	13.5 b
			MC1	15.7 a	12.6 b	14.6 a	13.8 a	12.9 a	15.1 b
	7 bar for 120 min	B	MC2	15.3 a	11.2 b	13.9 c	12.7 a	11.8 a	13.9 b
			MC1	16.0 a	12.5 b	14.5 c	13.2 a	12.8 a	14.6 b
		M	MC2	16.4 a	12.4 b	14.8 c	13.0 a	12.7 a	13.7 a
			MC1	17.3 a	13.8 b	15.3 c	15.5 b	14.1 a	16.0 b

B: Bottom; M: Middle; MC2 : 30 - 40%; MC1 : 15 - 20%; E1 & E2 : two ends ; E0: middle section.

Means having different letters in the same row are significantly different ($p \leq 0.05$)

Table 6b. Variation of retention (kg/m^3) for *D. asper* depending on the position of sampling

Preservative	Schedule		Sample condition	along culm			radial direction		
				E1	E0	E2	Outer	Center	Inner
BB	5.5 bar for60 min	B	MC2	6.1 a	4.6 b	5.9 a	4.9 ab	4.1 a	5.3 b
			MC1	6.3 a	4.8 b	5.8 a	5.8 ab	5.0 a	6.0 b
		M	MC2	6.9 a	5.0 b	6.4 a	5.9 ab	5.2 a	6.1 b
			MC1	7.5 a	5.7 b	7.1 a	6.2 ab	5.7 a	7.0 b
	5.5 bar for90 min	B	MC2	6.9 a	5.4 b	6.8 a	5.8 ab	5.4 a	6.5 b
			MC1	7.1 a	5.6 b	6.9 a	6.0 ab	5.8 a	7.3 b
		M	MC2	7.3 a	5.8 b	6.7 ab	6.4ab	6.2 a	7.2 b
			MC1	8.3 a	6.0 b	8.0 a	6.9 ab	6.5 a	7.5 b
	5.5 bar for120 min	B	MC2	7.3 a	5.7 b	7.0 a	6.1 a	6.0 a	7.4 b
			MC1	8.1 a	6.4 b	7.6 a	6.7 ab	6.5 a	7.7 b
		M	MC2	7.9 a	6.2 b	7.6 a	6.9 ab	5.9 a	7.1 b
			MC1	9.0 a	7.2 b	8.5 a	7.7 ab	7.4 a	8.3 b
CCB	7 bar for60 min	B	MC2	9.9 a	8.2 b	9.7 a	8.8 ab	8.2 a	9.5 b
			MC1	12.4 a	9.3 b	11.7 a	10.8 a	9.6 b	11.6 a
		M	MC2	10.9 a	8.9 b	10.4 a	9.3 ab	9.2 a	10.4 b
			MC1	12.8 a	10.4 b	11.9 a	11.7 a	11.4 a	12.0 a
	7 bar for90 min	B	MC2	12.2 a	8.8 b	11.3 a	9.7 ab	8.9 a	9.9 b
			MC1	13.5 a	10.7 b	13.0 a	11.6 a	11.2 a	11.9 a
		M	MC2	12.3 a	10.0 b	11.5 a	10.8 a	10.3 a	11.2 a
			MC1	13.6 a	11.2 b	13.0 a	12.1 ab	11.3 a	12.3 b
	7 bar for120 min	B	MC2	13.9 a	11.1 b	13.1 a	12.2 a	11.4 a	13.5 b
			MC1	14.2 a	11.4 b	12.8 c	12.6 ab	12.0 a	13.8 b
		M	MC2	13.3 a	11.5 b	12.8 a	12.9 a	12.0 a	13.3 a
			MC1	15.0 a	12.6 b	14.7 a	13.4 ab	13.0 a	14.5 b

B: Bottom; M: Middle; MC2 : 30 - 40%; MC1 : 15 - 20%; E1 & E2 : two ends ; E0: middle sectionMeans having different letters in the same row are significantly different ($p \leq 0.05$)

Table 6c. Variation of retention (kg/m^3) for *T. siamensis* depending on the position of sampling

Preservative	Schedule		Sample condition	along culm E1	along culm E0	along culm E2	radial direction Outer	radial direction Center	radial direction Inner
BB	4 bar for60 min	B	MC2	6.4 a	4.2 b	5.8 a	5.7 b	4.8 ab	4.5 a
			MC1	6.3 a	4.6 b	5.9 a	6.1 b	5.9 ab	4.9 a
		M	MC2	7.2 a	5.7 b	6.8 a	6.6 ab	6.0 a	7.2 b
			MC1	8.6 a	6.3 b	8.2 a	7.4 ab	6.6 a	7.7 b
	4 bar for90 min	B	MC2	5.9 a	4.5 b	5.5 a	5.9 b	5.1 ab	4.8 a
			MC1	7.5 a	5.3 b	6.87 a	6.9 b	6.1 ab	5.7 a
		M	MC2	8.5 a	6.0 b	7.7 a	6.7 ab	6.2 a	7.4 b
			MC1	8.8 a	7.1 b	8.2 a	8.3 ab	7.5 a	8.6 b
	4 bar for120 min	B	MC2	7.2 a	4.9 b	7.0 a	6.2 b	5.7 ab	5.2 a
			MC1	8.6 a	5.7 b	7.8 a	7.1 b	6.5 ab	6.3 a
		M	MC2	8.8 a	6.4 b	8.4 a	7.1 ab	6.5 a	7.8 b
			MC1	10.4 a	7.5 b	10.2 a	8.6 a	7.8 a	8.8 a
CCB	5.5 bar for60 min	B	MC2	10.5 a	7.8 b	9.75 a	9.8 b	8.7 a	8.2 a
			MC1	10.2 a	8.3 b	9.7 a	10.4 b	9.4 ab	8.6 a
		M	MC2	11.3 a	8.5 b	10.4 a	9.2 a	8.9 a	10.0 a
			MC1	13.4 a	10.6 b	12.8 a	11.3 a	10.8 ab	12.4 b
	5.5 bar for90 min	B	MC2	12.1 a	8.4 b	11.7 a	11.0 b	9.5 a	9.1 a
			MC1	12.4 a	9.7 b	11.4 a	12.5 b	11.8 b	10.2 a
		M	MC2	12.7 a	9.8 b	12.1 a	10.9 ab	10.0 a	11.4 b
			MC1	15.5 a	11.6 b	14.4 a	13.4 a	12.0 b	14.1 a
	5.5 bar for120 min	B	MC2	14.5 a	10.2 b	14.2 a	13.3 b	12.7 b	10.5 a
			MC1	15.3 a	11.7 b	14.0 c	14.7 b	13.8 ab	12.9 a
		M	MC2	14.5 a	10.3 b	13.8 a	11.5 ab	10.6 a	11.8 b
			MC1	17.5 a	12.6 b	16.4 a	14.1 ab	13.0 a	14.4 b

B: Bottom; M: Middle; MC2 : 30 - 40%; MC1 : 15 - 20%; E1 & E2 : two ends ; E0: middle sectionMeans having different letters in the same row are significantly different ($p \leq 0.05$)

culm wall, the highest retention occurred at the inner layer, followed by the outer layer and the center. This result is confirmed by Kumar *et al.* (1992).

The higher retention at the ends as well as in the outer and inner layers of the culm part will be beneficial in service since these parts come first in contact with fungi and insects.

CONCLUSIONS

The preservative absorption of the three bamboos investigated had a distinct dependence on the species, the culm portion, the preservative and especially on the pressure and time applied. Significant linear relationships between them were indicated to provide information, which could be applied in determining the treatment schedule for these species.

From a practical point for reducing seasoning time, a moisture range of 30 - 40% could be used instead of 15 - 20% moisture as sometimes applied.

Considering these results with the recommendations of 4 kg/m^3 boron compound for indoor furniture and 10 kg/m^3 CCB for outdoor exposure (Liese and Kumar, 2003), the following treatment schedule is recommended:

For indoor use with BB, *T. siamensis* needs a pressure of 4 bar for 60 min., whereas for *B. stenostachya* and *D. asper* 5 bar for 60 min. is required.

For outdoor application with CCB, *T. siamensis* demands a pressure of 5.5 bar for 120 min., but *B. stenostachya* and *D. asper* need 7 bar for 60 and 120 min., respectively.

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